ANALYSIS OF FRONTAL BOUNDARIES BY MEANS OF THICKNESS ANOMALIES, NOVEMBER 12–16, 1956

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1. INTRODUCTION

The National Weather Analysis Center (NAWAC) for the last four years has used the gradient discontinuity on the 1000–500-mb. thickness chart as a criterion for the existence and intensity of a front. However, when a frontal discontinuity lies in an area of strong normal thickness gradient, the magnitude of the normal gradient can obscure the thermal gradient caused by the presence of the front. Or inversely, the strong normal thickness gradient frequently can suggest the existence of a front when none is present. Thus, it seems logical to subtract the normal thickness gradient from the synoptic thickness gradient to obtain the frontal thickness gradients. This subtraction is made on a routine basis at NAWAC to obtain the 1000–500-mb. thickness anomaly analysis for other uses.[1] The gradient discontinuities of these thickness anomaly contours also can be used to aid in establishing a position and intensity of the frontal zones [1].

The above concepts can be expressed as follows [2]:

$$\nabla Z = \nabla Z' + \nabla Z_\delta, \text{ and}$$

$$\frac{\partial}{\partial y}(\nabla Z) = \frac{\partial}{\partial y}(\nabla Z') + \frac{\partial}{\partial y}(\nabla Z_\delta)$$

where Z=1000–500-mb. thickness

Z'=normal 1000–500-mb. thickness

Z_δ=departure from normal 1000–500-mb. thickness

∇=horizontal gradient operator.

When the gradient of the normal is uniform, then

$$\frac{\partial}{\partial y}(\nabla Z') = 0, \text{ and } \frac{\partial}{\partial y}(\nabla Z) = \frac{\partial}{\partial y}(\nabla Z_\delta)$$

that is, the component change of thickness gradient is equal to the component change of thickness anomaly gradient, and any discontinuity of one gradient is equal to the discontinuity of the other. Since the strongest 1000–500-mb. thickness gradient discontinuity lies along the front, the strongest anomaly gradient discontinuity will also lie along the front. When $\partial (\nabla Z')/\partial y$ is not zero, i. e., when the gradient of the normal is not uniform, the front can lie along the discontinuity in the normal gradient without showing an anomaly gradient discontinuity.

The southwestern part of North America and the adjoining Pacific Ocean is an area in which there is a strong climatological thickness gradient. The synoptic situation of November 12–16, 1956, is used in this article to illustrate how the thickness anomaly gradient aids frontal analysis in this area.

2. THE COLD FRONT AND THE THICKNESS ANOMALY

Preceding this situation unseasonably high temperatures were recorded in the southwestern United States. Los Angeles reached 95° F. on November 9; Winnemucca 74° F. on the 10th; Prescott 75° F. on the 11th; all were near or above record for the date. Subsequent to the passage of the cold front under discussion, Prescott measured a record minimum of 15° F. for the date on November 15.

On November 12 at 0630 GMT (fig. 1A) there was a front lying from western Lake Erie through Oklahoma and the Texas Panhandle into Wyoming, then westward through northern Oregon off the coast to 46° N., 130° W. and then southwestward. The portion of the front from 46° N., 130° W. southwestward is the subject of this discussion. At this time the 1,000–500-mb. anomalies (fig. 1B, solid lines) showed above normal thickness over the western United States. This was associated with the abnormally warm surface temperatures throughout the area of the Plateau High.

Behind the cold front in the Pacific there was a strong thickness gradient and a parallel strong thickness anomaly gradient. There was also a moderate thickness gradient through New Mexico, Arizona, southern Nevada and central California suggesting a front somewhere near the southern edge of this gradient. However, the reverse anomaly gradient indicates that the thickness gradient there was less than normal.

At 0630 GMT of November 13 (fig. 2A), the cold front under discussion had moved to a position through north-

[1] The routine at NAWAC for deriving the thickness anomaly analysis utilizes graphic subtraction techniques. The monthly normal contours are traced with grease pencil upon a sheet of clear acetate. Then this acetate is overlaid upon the synoptic thickness analysis acetate and graphic subtraction is performed onto a third acetate.

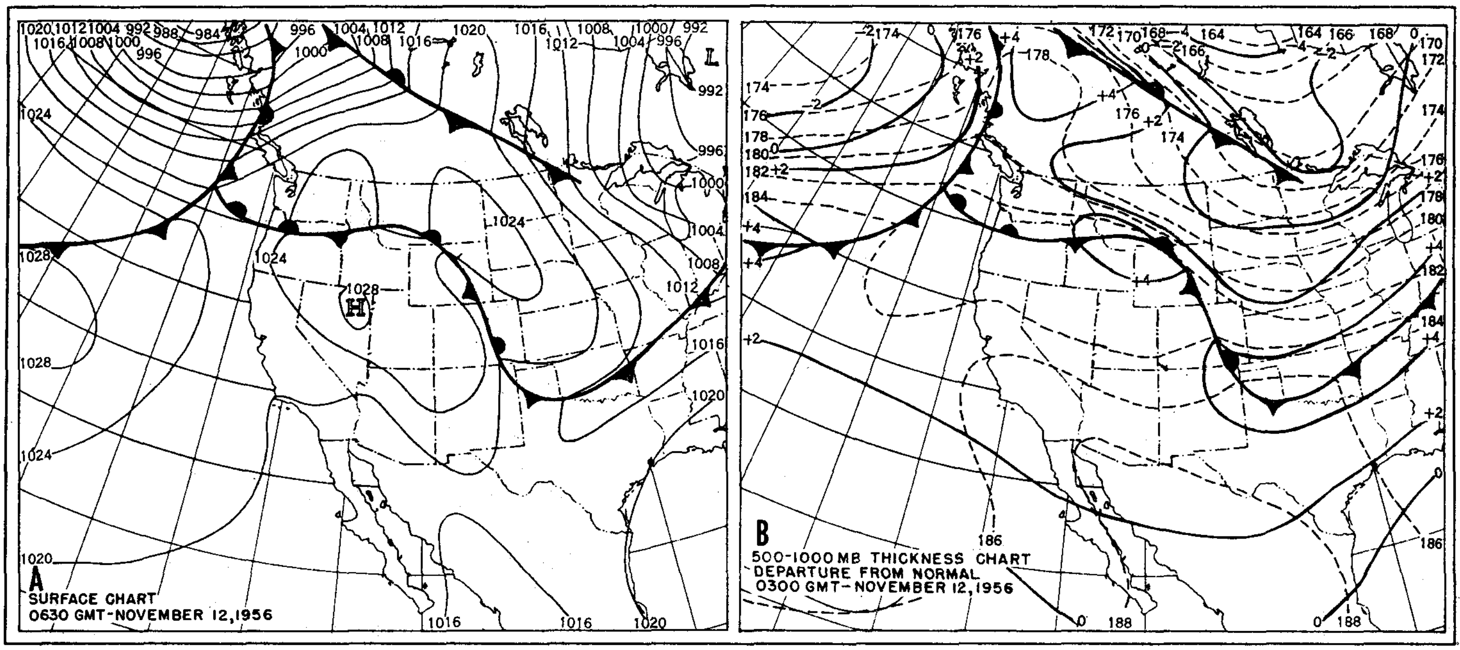

Figure 1.—November 12, 1956. (A) Surface fronts and isobars, 0630 GMT. (B) 1000–500-mb. thickness contours (dashed lines) and their departure (solid lines) from November thickness normals, 0300 GMT.

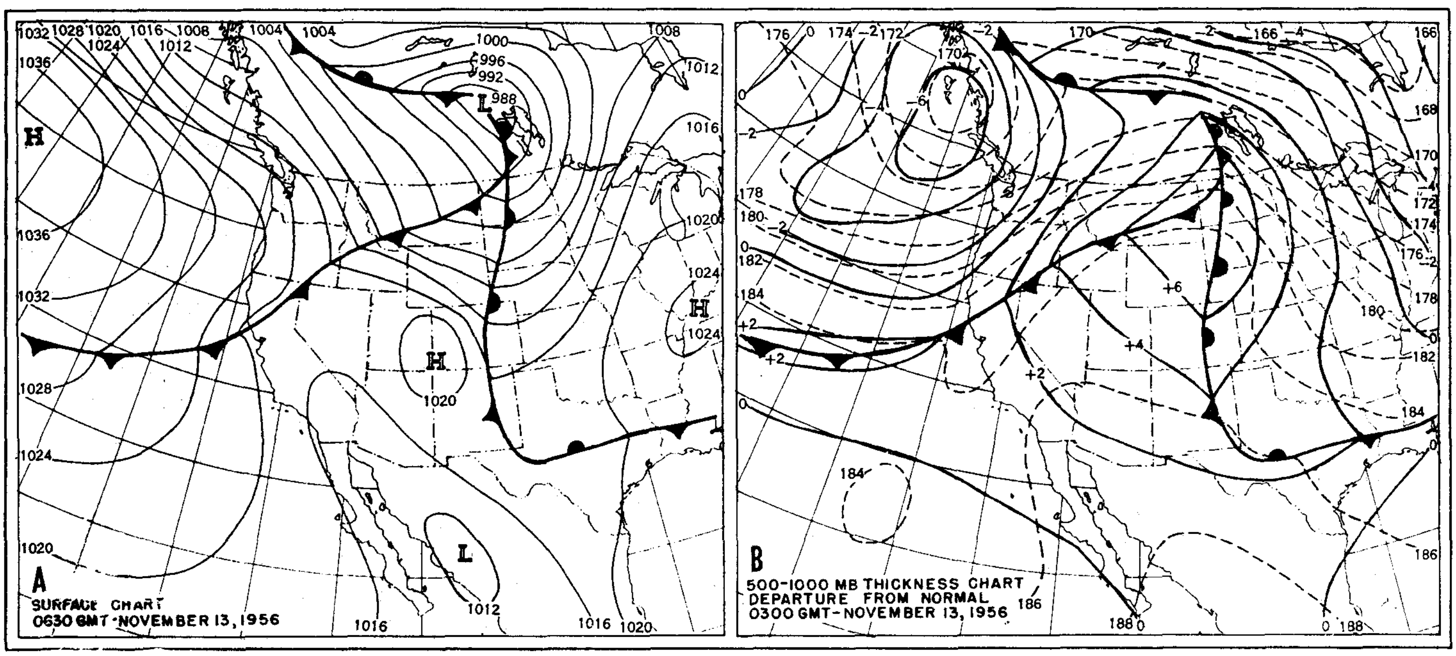

Figure 2.—November 13, 1956. (A) Surface fronts and isobars, 0630 GMT. (B) 1000–500-mb. thickness contours (dashed lines) and their departure (solid lines) from November thickness normals, 0300 GMT.

western North Dakota, Montana, central Idaho, southeastern Oregon, northern California, and southwestward to 35° N., 130° W. The thickness gradient discontinuity (fig. 2B, dashed lines) across this front leaves no doubt as to its existence or intensity. The components of the anomaly gradients parallel to the thickness lines also show a sharp discontinuity.[2] Also, any other considerations leave little or no area of doubt in the position of the front at this time; pressure tendencies, cloud forms, precipitation, wind shifts, temperature changes, radiosonde, rawin changes, etc., all confirm the position. An examination of the departure from normal 1000–500-mb. thickness chart shows that it is not the scalar magnitude of the

[2] To investigate the components of the gradients parallel to a portion of a front, the following graphic technique can be used: (1) Using two copies of the 1000-500-mb. anomaly contours (analyzed in 200-ft. intervals), displace one from the other by a distance equal to the geostrophic spacing for 25 knots and in the direction perpendicular to the front. (2) Subtract graphically. The resulting contours are isotachs of the geostrophic spacing of the component of 1000-500-mb. anomaly parallel to the front in 25-knot intervals.

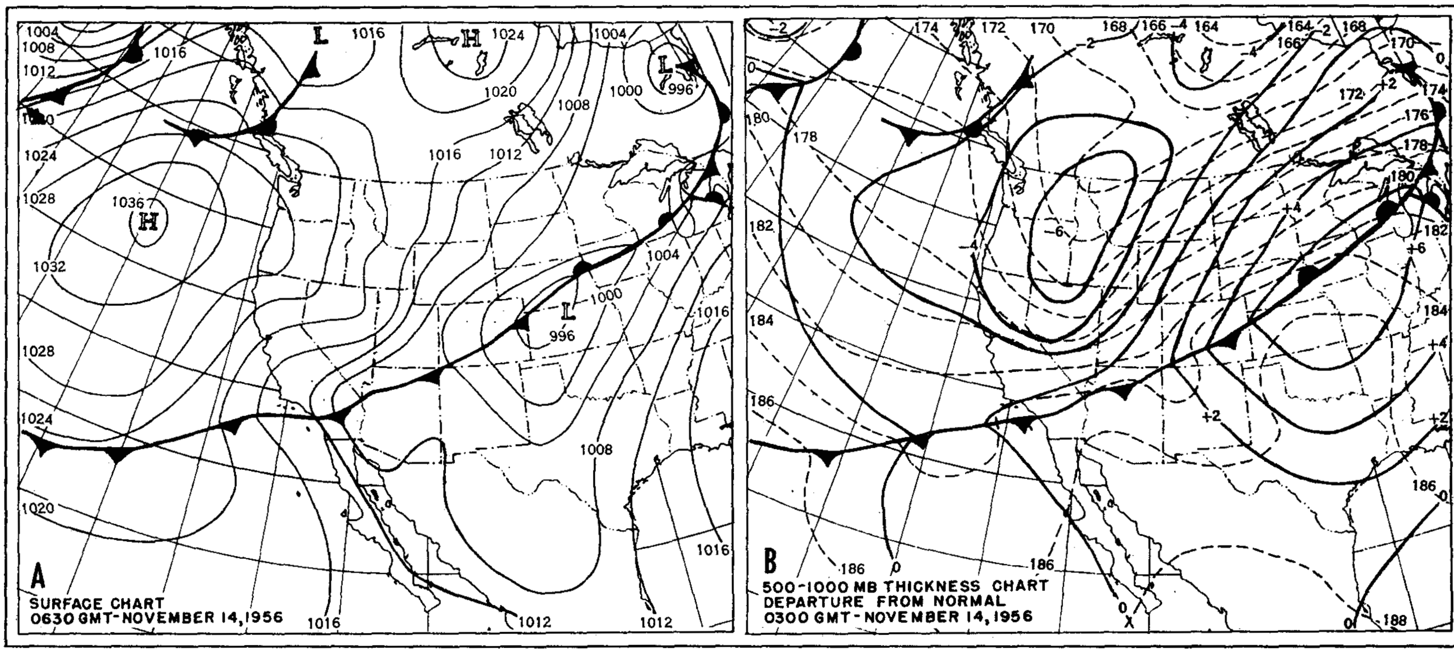

FIGURE 3.—November 14, 1956. (A) Surface fronts and isobars, 0630 GMT. (B) 1000–500-mb. thickness contours (dashed lines) and their departure (solid lines) from November thickness normals, 0300 GMT.

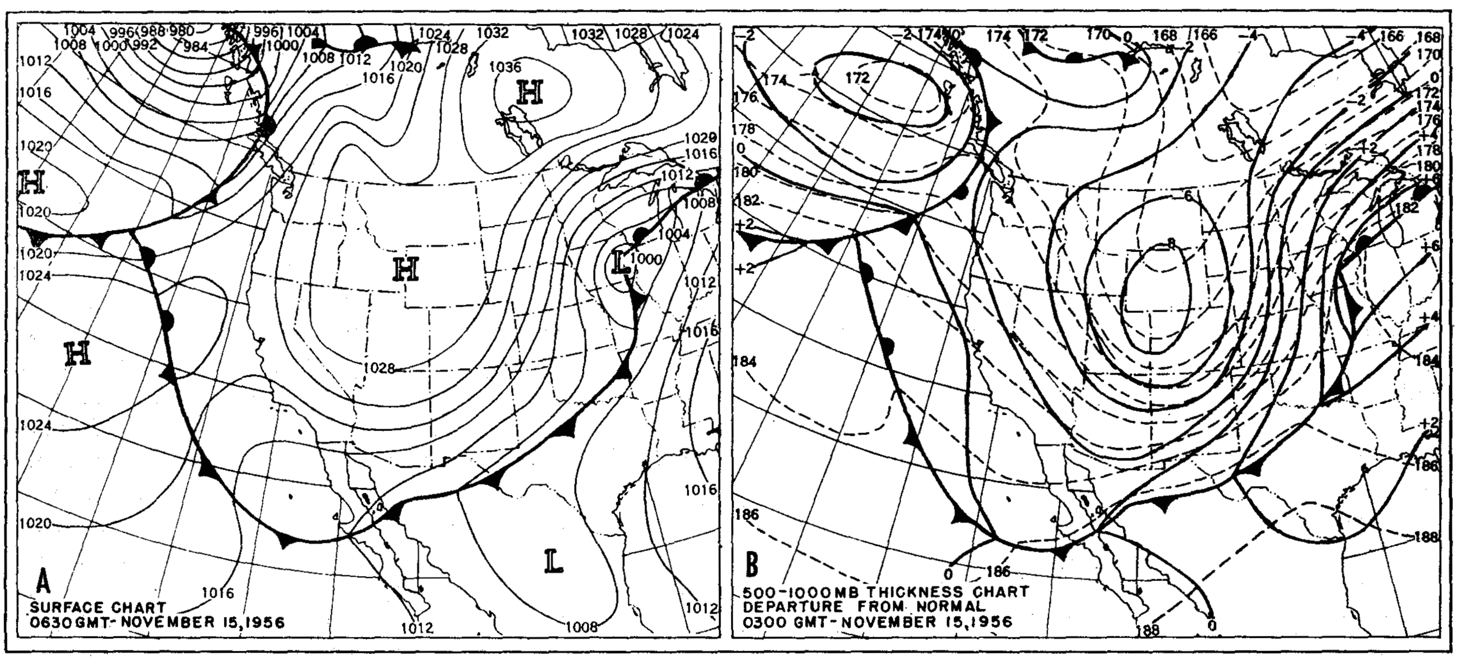

FIGURE 4.—November 15, 1956. (A) Surface fronts and isobars, 0630 GMT. (B) 1000–500-mb. thickness contours (dashed lines) and their departure (solid lines) from November thickness normals, 0300 GMT.

anomaly field which is important to delineate the frontal boundary, but rather the vector difference of the components of the gradients parallel to the front which is important. For example, in figure 2B through Nevada, southern Idaho, and Wyoming, the departure from normal contour gradient is perpendicular to the front, so that any component parallel to the front is zero. North of the front the component parallel to the front is large.

On November 14 at 0630 GMT (fig. 3A), the front lay from Lake Michigan through Nebraska, northern Arizona, and southern California, and west-southwestward off the coast. The 1000–500-mb. thickness gradient discontinuity clearly defines the front over most of the area (fig. 3B, dashed lines). The small cold protrusions ahead of the front in New Mexico and off the coast, might seem significantly contradictory. However, in both these

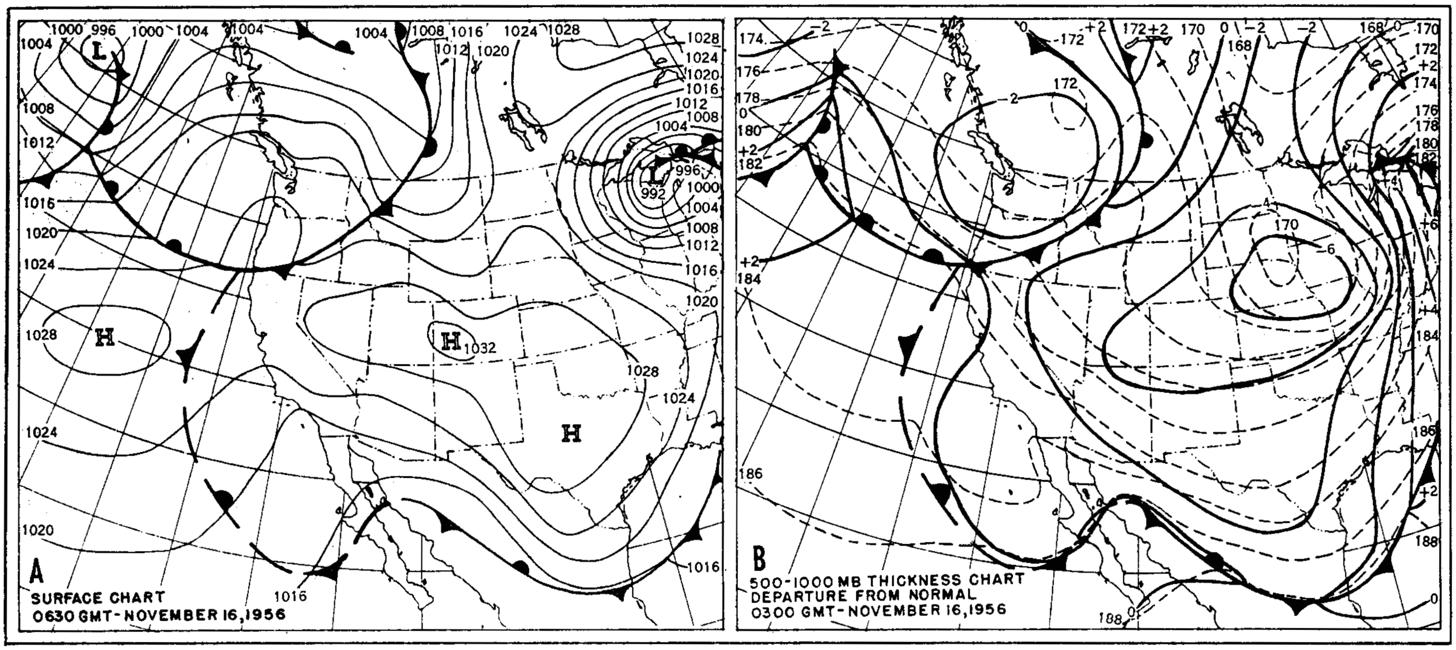

FIGURE 5.—November 16, 1956. (A) Surface fronts and isobars, 0630 GMT. (B) 1000–500-mb. thickness contours (dashed lines) and their departure (solid lines) from November thickness normals, 0300 GMT.

areas the 1000–500-mb. thickness departure from normal gradient (fig. 3B, solid lines) was perpendicular to the front south of the front, with a strong component parallel to the front north of the front. Furthermore, of all the strong departure from normal gradient south of the front over New Mexico, Texas Panhandle, and Kansas, none of the component parallel to the 1000–500-mb. thickness contours is appreciable.

At 0630 GMT of November 15 (fig. 4A), the cold front was located from Iowa to southeastern Oklahoma to western Texas, through northern Mexico, central Lower California, off the coast to 26° N., 117° W., and then northwestward. Here again the 1000–500-mb. thickness gradient discontinuity (fig. 4B) locates the front quite well over most of its length. From the southern border of Texas westward the 1000–500-mb. thickness departure from normal contours aid in showing the reality of the front. Offshore, both the thickness and the thickness anomaly gradient began to weaken and the front became difficult to locate.

The cold front reached its southernmost position on November 16. At 0630 GMT (fig. 5A), it lay from southeastern Mississippi and Louisiana southwestward through the western part of the Gulf of Mexico to the east coast of Mexico at 23° N., then northwestward to the northern Gulf of California. The 1000–500-mb. thickness and the 1000–500-mb. departure from normal thickness gradients (fig. 5B) still define this portion of the front quite well. However, the lack of anomaly gradient off the west coast demonstrates that any 1000–500-mb. thickness gradient in that area is purely climatological, so that the front can be frontolized.

The Plateau High was again established but at this time the High exhibited much colder temperatures than were observed prior to November 12.

3. CONCLUSIONS

Sutcliffe and Forsdyke said [3], "Any thickness line has a mean seasonal position, which can be represented by mean charts, and departure from the mean position is an immediate and significant indication that physical processes are operating to maintain the temperature anomalies." Specifically, there is considerable information about frontal discontinuities to be gained from a consideration of the contour gradients of the thickness anomaly chart. The subtraction of normal thicknesses from the synoptic thickness chart leaves more obvious the gradient discontinuity caused by a front. A cursory examination of the day-by-day relationships between the fronts and the anomaly patterns suggests the following conclusions:

(1) A sharp front with a strong thickness discontinuity shows also a strong anomaly gradient discontinuity.

(2) The scalar magnitude of the anomaly field is of no significance in delineating a front. The vector difference of the components of the gradients parallel to the front is the only important measurement.

(3) There are some areas of the normal thickness chart which contain contiguous gradient differences of sufficient magnitude to suggest the existence of a front. In these areas the anomaly gradient can be near zero when the front lies along this normal thickness gradient discontinuity. Thus, a thickness departure from normal gradient discontinuity can be said to be a sufficient but not necessary criterion to define a frontal discontinuity.

(4) A better tool than a normal thickness chart for deriving an anomaly would be a normal tropical-air thickness chart. This chart should be an average of thickness measurements made exclusively south of the polar front at each station. Sutcliffe's [3] extreme maximum charts approximate these normals except that they represent the one extreme maximum instead of the average of many warm situations. The contours of the departures from this normal tropical-air chart would better show the frontal boundary between the polar and tropical air.

4. SUMMARY

There are times and areas when the synoptic thickness gradient discontinuities associated with the presence of a front are not obvious to the analyst, because of the existence of a strong climatological temperature gradient. For many of these times, as illustrated by the case of November 12–16, 1956, consideration of the thickness anomaly gradient discontinuities is a helpful procedure.

ACKNOWLEDGMENTS

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